Transportation procurement support using Data Envelopment Analysis*

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Abstract

This paper presents a method[1] for a shipper to screen and choose carriers in a Request For Proposals (RFP) and set up enduring relationships with them. The screening is done using a frontier analysis model (inscribed within Data Envelopment Analysis or DEA). The method is compared to a traditional method of selecting carriers through a Mixed Integer Linear Program (MILP).

Keywords

Auction, efficiency, transport.

1 Introduction

The problem with the traditional method of assigning carriers to lanes on the basis of their bids on ex ante notional volumes of cargo to trans-

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[1]The results presented here stem from a working paper co-written with my thesis supervisor and Professor Peter Bogetoft from the Department of Economics in Copenhagen Business School, Denmark.

port is that the shipper is unable to discriminate between those who will truly be delivering the best effort and those who may engage in opportunistic behaviour or otherwise deliver a sub-par service. How is she to defend herself against carriers being chosen on low prices and in the future take advantage of demand or other externalities to hold her up?

The point is to select a group of carriers which will be admitted to bidding in a second round on the basis of their situation on an efficiency frontier in a multi-dimensional space. The starting point of this research was the observation of a real case in a RFP at a big retailer in Argentina. This chain counted around 44 supermarket-sized stores outside of the Buenos Aires conurbation and worked without any formal contract with a large number of different transport firms of several types and sizes for deliveries to the rest of the country. To unify its distribution and homogenize its transport supplier pool, it described the delivery schedule to a total of 42 destinations. The products to be transported required 3 types of transport: chilled for meat and dairy products, temperature controlled for vegetables and fresh produce and ambient curtain-siders for ordinary groceries. A schedule with distances, hours of departure, hours of delivery and weekly frequencies was annexed to the tender. 25 carriers (who first had to qualify technically on regulatory, security and fleet requirements) responded, some of which were already suppliers to this chain, others who were not. All respondents tendered partially: bids covered either some localities or category of goods or some frequency. In all, 318 bids for a number of trips per year at a given price each for full truck loads of 24 pallets were received.

The logistics manager in charge of choosing the winner filled the categories and frequencies according to a ranking of the lowest bids after dropping outliers and suspiciously low bids. Comparisons were done with actual prices paid by a benchmarking bread manufacturer and another retail chain (from the same holding company) for similar trips. The new selection of suppliers and the implied overall transport cost was compared to the existing transport cost before the auction. The resulting reduction in the number of suppliers and the overall reduction in transport costs were considered sufficient justification for this exercise.

We wish to try and compare this old tried-and-tested method with a new one using efficiency frontier analysis.

We relied on the Monte Carlo method to obtain comparable results.

We consider the case where the principal (shipper) faces uncertainty about the technology. In a single input multiple output cost setting, she may for example know that the cost function is increasing and convex, but otherwise have no a priori information about the cost structure, letting the agent (carrier) potentially charge above the economic rate of return. In the bidding context, we can interpret this slack term added to the optimal cost as an information rent (potentially) charged by the agent. We consider the possibility that the agents have superior information about the working conditions, before contracting with the principal. A carrier may for example have private information about the return cargo for the trip back of a specific route. This leads to the classical adverse selection problem, where an agent will try to extract information rents by claiming to be operating under less favorable conditions. Moreover, the agents may also try to strategically exploit market incomplete information to claim extra rents for routes, goods and other services that are subject to lower competitive pressure.

The remainder of the chapter is organized as follows, in § 2, we review some literature relative to the proposed approach, in § 3 we present the models which we use here. In § 4, we give the results from each model, in § 5 we give a managerial interpretation of the outcome as could be applicable to shippers and carriers alike. We conclude in § 6.

2 Literature review

2.1 Auctions in transport procurement

Literature mostly deals with auction design without consideration of the carrier selection process or with combinatorial optimization of assignments under different constraints leading to solving a Mixed Integer Linear Program.

A number of papers dating back to Friedman (1956) have considered the situation faced by bidders who wish to bid on a number of differentiated items that are to be sold with simultaneously opened bids but who face a constraint upon the total of their bids. Bundled bids for goods who have more value to a bidder as a bundle than taken separately have also been dealt with in the cell phone licence public auctions[2]. These auctions take into account interdependencies internal to bidding firms. External interdependencies should also be taken into account as they are represented, in the case of the transport industry, by preventive or predatory bidding by carriers on routes served by larger or better connected carriers to disrupt their established network of lanes or routes. Elmaghraby and Keskinocak (2004) present a teaching case where The Home Depot in the United States actively solicited and provided the necessary tools for carriers to combine bids for routes for the auction of a forecast total of 52 000 loads over 623 lanes. This same example is showcased to highlight the difficulties in selecting the winning bids in a combinatorial auction as a chapter in Elmaghaby and Keskinocak (2003).

The interest of our approach is to obtain information from the real bids put in from the carriers so that a shipper can achieve a more sincere notion of the real intrinsic perception of each carrier's position on a technological efficiency frontier. It is to be pointed out, however, that this approach does not purport to explicitly identify or evaluate the economies of scope achieved by a carrier when he wins a set of lanes, as defined by Panzar and Willig (1981) and used by Díaz (1982).

In effect, as has been clearly identified (Klemperer, 1999, Caplice and Sheffi, 2003, Chen, 2001), the traditional auction mechanism and bidding processes – the English sealed bid single-round auction – do not allow the reservation or most efficient bids that the carrier would be willing to offer to be signalled to the shipper. In fact, the carriers for want of sufficient information will artificially pad their bids to protect themselves against uncertainty arising from a host of business and reputation issues.

Moreover, a carrier will be more interested in submitting a bid if the traffic generated meshes well with his other lanes and frequencies. This phenomenon is best captured when the auction is designed to favor

[2]In which case the goods to be bid upon exhibit "superadditive" values or synergies when their value is more together than the sum of their individual values.

combinatorial bids (Kwon et al., 2005). The network interdependency generated from a network of lanes and frequencies has been modeled in Díaz and Basso (2003).

Transport is an especially interesting area to which apply combinatorial auctions because of the enhanced value of combining several lanes with the existing network of lane and backhaul possibilities for a carrier. Kelly and Steinberg (2000) represent a nice introduction to the key aspects of a combinatorial auction and give complete references to previous work. Pekeč and Rothkopf (2003) give a good guide to designing a combinatorial auction including the pitfalls to be avoided. Gallien and Wein (2005) deals with multi-item auctions for a monopsonistic buyer and capacity constrained suppliers by designing a "myopic best response" mechanism to reduce supplier computational burden. However in this stream of literature, the sole preoccupation of the auction organizer is cost to the detriment of quality or other considerations.

2.2 Multi-dimensional auctions

Although there are many practical instances of multidimensional auctions, e.g. the conservation reserve program in the USA (cf.e.g. Vukina and Wossink, 2000), or the Department of Defence procurement auctions for weapon systems in the USA, (cf. e.g. Che, 1993, Bichler, 2000, Beil and Wein, 2003), the theoretical literature on multi-dimensional auctions is sparse.

In a standard auction or procurement context, where a single quality product is supplied, the revenue equivalence between first price and second price auctions is the most central result. It was suggested by Vickrey (1961), but remained a puzzle until 1981 where Riley and Samuelson (1981) and Myerson (1981) simultaneously solved the problem. They show that in an independent private value model, the different mechanisms give the same expected revenue (or costs) to the principal.

Che (1993) shows how the existing theory can be generalized to multidimensional auctions. He considers allocating contracts containing a price p and a one-dimensional quality parameter q. The principal's concave utility function is monotonous in the quality indicator $V(q)$. An agent DMU_i that wins a contract earns profit

$$\pi_i = p - C(q, \tau),$$

where p is the price he is paid, q is the quality he must deliver, τ is his type and $C(q, \tau)$ is his costs of producing quality q. The principal selects a quasi-linear score function: $S(p, q) = V(q) - p$. The agents with highest scores are offered a contract. The exact terms of the contracts depend on which mechanism is chosen. Che (1993) considers two different mechanisms:

- First score auction - the bidder with the highest score wins and has to comply with the highest quality standard. A first score auction can be compared with the first price auction.
- Second score auction - the bidder with the highest score wins and has to comply with the second highest quality standard. A score auction can be compared with the second price auction.

He shows an equivalence theorem for the two types of score auctions. Both auctions are optimal second best mechanisms.

2.3 Data envelopment analysis

However, these auctions often do not enable bidders to put in combined bids. A case in point is the auction which is presented here. This is why we have found interesting to introduce a new potential use of DEA, namely to evaluate non-realized multi-dimensional bids (as opposed to realized production plans) in a procurement setting (as opposed to a control setting). In particular, we suggest that an allocation and price setting mechanism along the lines of the DEA based yardstick schemes, can be a useful generalization of a second price sealed bid auction mechanism.

There is also a great amount of literature on relative performance evaluations (see van Donselaar et al., 1998, for the results of a survey of the critical success factors of transport and distribution companies in Europe). This has been an important theme in the agency literature ever since the seminal contribution of Holmstrom (1982). The extension to multiple dimensional performances and the combination with frontier models like DEA was initiated in Bogetoft (1997, 2000) and expanded upon in Agrell et al. (2002, 2005). Performance based payment schemes, where a manager's bonus depends on his performance relative to the sector or the market in general, is a prime example. The first conjectures as to the likely responses to DEA control, go back to Banker (1980) and Banker et al. (1984). They provided game theoretical interpretations of the scoring problem in the standard DEA models given realized inputs and outputs. The study of the ex ante motivation game of choosing inputs, outputs, efforts, skills etc using formal agency models was initiated by Bogetoft (1990). One result which interests us concerns the design of incentives for risk neutral agents in a context with considerable technological uncertainty and asymmetric information about a regulated agent's actions (moral hazard) and working conditions (adverse selection), cf. Agrell and Bogetoft (2001) and Bogetoft (1997, 2000), and in a dynamic setting Agrell et al. (2002).

3 Models

Let us assume that the principal is risk neutral and that the agents are either risk averse or risk neutral. The principal's aim is to minimize the costs of inducing the agents to take the desired (hidden) actions in the relevant (hidden) circumstances. An agent's aim is to maximize the utility from payment minus the disutility from his private effort.

We consider that the shipper incurs a fixed cost of operation which is proportional to the number of carriers she works with. To further refine the comparison between both models, we have added a capacity constraint on the volume they could carry upon realization of demand. In the first case, the carriers have tendered for a certain number of trips per lane but upon realization of demand, they comply with the additional requests of the shipper over their trip number that they bid by adding capacity (possibly by subcontracting from third parties or diverting capacity from some other customer). In the second case, the carrier cannot exceed the number of trips he committed himself to.

In the following two subsections, we present a model using the efficient frontier analysis and a model using a simple mixed integer linear program to minimize the cost of transport using the characteristics described in the ex ante tender.

3.1 Efficient Frontier model

The idea behind a frontier analysis model, as the non-parametric Data Envelopment Analysis, is to create a piecewise linear cost function using minimal extrapolation in order to compare carriers, as independent Decision Making Units (DMU), across units and/or over time. The approach has wide application areas since it does not require any *a priori* structural assumptions on the cost function, nor preference information.

The frontier analysis method, considering the bids as bundled bids, may have several motivations. On the shipper's side, he may be interested in only working with a limited number of carriers to limit transaction and relationship specific costs. Moreover, and more intricate, he may look for bundled bids as a way to lower information rents. It is well known that when an agent produces multiple products under asymmetric information, and even if there are positive externalities for the agent, it may pay for a principal to buy in bundles since it provides an instrument to undermine the informational advantage of the agent, cf. e.g. Antle et al. (1999). The carriers, Decision Making Units (DMUs), on the other hand may anticipate that the shipper will buy in bundles and they may submit prices that reflect this. That is, even if the bids are officially submitted on a route base, the carriers may have included discounts (sharing mechanisms) for part of the synergies that may be involved. The shipper may also in this way accommodate her inability to forecast the demands correctly. When demands are unknown, the shipper allocates them to the carrier per order of efficiency.

To formalize the above, each of n DMUs, say DMU^i, is assumed to transform m_x controllable inputs x^i into m_y outputs y^i. The prices, if existing, on the controllable inputs and outputs are $w^i \in \mathbb{R}_+^{m_x}$ and $p^i \in \mathbb{R}_+^{m_y}$.

We assume that the technological possibilities are the same for all DMUs' (except for the differences captured by the non-controllable) variables. Specifically, these possibilities may be thought of as the set T of feasible input-output combinations

$$T = \{(x, y)|(x,) \text{ can produce } y\}$$

It shall be assumed that generally T satisfy

Condition 1. *Free disposability:* $(x, z, y) \in T, x' \geq x, 0 \leq y' \leq y \Longrightarrow (x', z', y') \in T.$

Condition 2. *Convexity:* T *is convex.*

Condition 3. r *returns to scale,* $(x, y) \in T \Longrightarrow (qx, qy) \in T, \forall q \in K(r)$ *,where* k *="*crs*","*drs*", or"*vrs*", and* $K(crs) = \mathbb{R}_0, K(drs) = [0, 1]$ *and* $K(vrs) = \{1\}$*, respectively.*

The associated underlying cost model for a DMU is given by

$$C(y|w) = \min_x \{wx|(x, y) \in T\}$$

Given n observations of feasible production plans (x^i, y^i) the *DEA based cost norm* for a DMU facing input costs w and non-controllable inputs z is

$$C^{DEA}(.|., .) : \mathbb{R}_0^{m_y} \times \mathbb{R}_0^{m_x} \rightarrow \mathbb{R}$$

defined as

$$\begin{aligned} C^{DEA}(y|w) = \quad & \min wx \\ & x, \lambda \\ & s.t. \quad x \geq \textstyle\sum_{i=1}^n \lambda^i x^i \\ & \qquad y \leq \textstyle\sum_{i=1}^n \lambda^i y^i \\ & \qquad \lambda \in \Gamma(r) \end{aligned} \tag{1}$$

where

$$\Gamma(crs) = \mathbb{R}_0^n,$$
$$\Gamma(drs) = \left\{ \lambda \in \mathbb{R}_0^n | \sum_i \lambda^i \leq 1 \right\},$$
$$\Gamma(vrs) = \left\{ \lambda \in \mathbb{R}_0^n | \sum_i \lambda^i = 1 \right\}.$$

The DEA based cost function gives the minimal cost of producing the output for any output vector given the local factor prices and the local non-controllable conditions.

If the inputs are unknown and the prices known, one may view the procurement problem in a different manner: one wishes to explore the maximum output given known prices and unknown inputs. This situation naturally translates to the ***DEA output-oriented problem*** for a DMU offering a total bid x for an offer y is $F^{DEA}(.|.) : \mathbb{R}_0^{m_y} \to \mathbb{R}$ defined as

$$
\begin{aligned}
F^{DEA}(y|z) = \quad & \max \quad \phi \\
& \phi, \lambda \\
& s.t. \quad x \geq \textstyle\sum_{i=1}^{n} \lambda^i x^i \\
& \qquad \phi y \leq \textstyle\sum_{i=1}^{n} \lambda^i y^i \\
& \qquad \lambda \in \Gamma(r)
\end{aligned}
\tag{2}
$$

The output-oriented problem corresponds to the radial expansion of the offer y to a competitive offer ϕy at the same or lower cost x.

3.2 Intuition

The way the production possibilities in DEA are estimated has several implications. The use of the minimal set containing the actual points, suggests that DEA provides an inner approximation of the underlying production possibility set. The (in) efficiency estimates are therefore cautious or conservative in the sense that the potential output expansions or input savings are underestimated. This can be seen for Decision Making Unit (DMU) D in figure 1 where the expansion possibilities were estimated as 30% with T^* and 100% with T.

The use of the minimal extrapolation principle and hereby, the construction of the largest inner approximation, also implies that the technology identifies so-called "best practice". This is attractive in many cases, since the methods and procedures of the best units are more likely targets for other units. Thus, for example, if D in figure 1 is to learn, it would probably find little to learn from looking at F. It would be more interesting to look at what units like B and perhaps E have done differently. A further consequence of using the DEA approach is that real peers are identified. In figure 1, D has two peers, B and E, since $F2$ is located on the line between these two units. B is the primary peer, since $F2$ is located close to B.

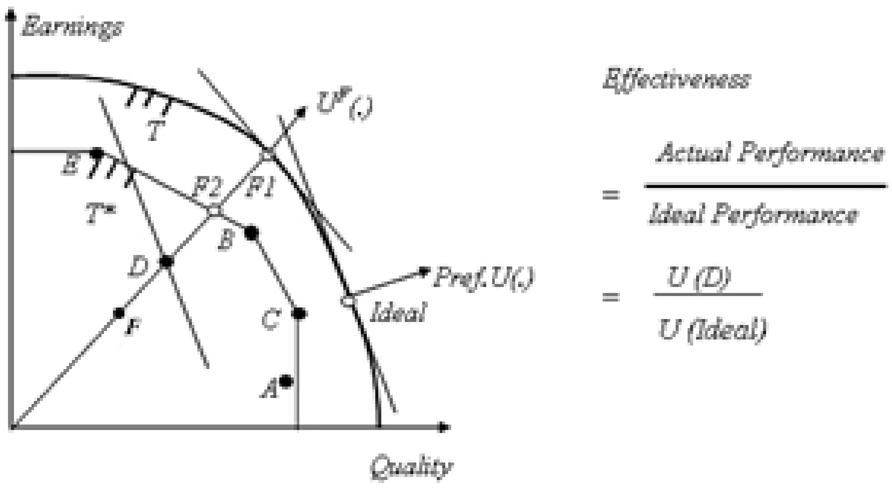

Figure 1: The rational ideal evaluation

3.3 Assignment model

The usual method employed to assign carriers to lanes is a mixed integer linear program of which we have derived two models. In the first, the carriers are considered as uncapacitated. This means that they are chosen, independently from the volumes that they will have bid for, purely on the basis of their bid. They are considered to be able to subcontract the required capacity when the realized demand exceeds their capacity. This, of course, reduces the choice to just one carrier per lane: the lowest bidder.

The second model assigns the lanes to the carriers taking into consideration their capacity offer (here, this translates into a frequency of trips per period on the given lane). When the lowest bidder does not offer sufficient trips, the next lowest is offered the remainder, etc, until all trips required for that lane are fulfilled.

The decision variable is the number of trips assigned to a carrier j within the m that submitted bids on a lane i of n that were offered for tender. The other variables are:

$$\begin{cases} b_{i,j} & \text{: price per trip bid by carrier } j \text{ on lane } i; \\ c_{i,j} & \text{: number of trips bid by carrier } j \text{ on lane } i; \\ r_i & \text{: required number of trips on lane } i; \\ car_j & \text{: 1 if carrier is included in pool of suppliers, 0 otherwise;} \\ B_k & = \sum_j^m car_j; \\ F_k & \text{: fixed cost of operating with a carrier.} \end{cases} \tag{3}$$

3.3.1 Uncapacitated model

The decision variable here is

$$x_{i,j} \quad \text{: binary: assigned to carrier = 1, 0 otherwise } j \text{ on lane } i; \tag{4}$$

The constraints are written as

$$\begin{cases} \sum_j^m x_{i,j} \geq 1, & \forall i, \\ \text{if } c_{i,j} = 0, \Rightarrow x_{i,j} = 0, & \forall i, \forall j, \\ \sum_i^n x_{i,j} \leq car_j * 40, & \forall j, . \end{cases} \tag{5}$$

The first constraint specifies that all requirements for each lane be covered. The second constraint specifies that no lane be attributed to a carrier that did not bid on it. The last one says that if a carrier is included in the pool of suppliers, he must not get more than 10 lanes.

The objective function is a cost minimizing one:

$$C_{uncap} = \min \big(\sum_i^n r_i \sum_j^m (x_{i,j} b_{i,j}) + B_k F_k \big), \tag{6}$$

where B_k is the total number of carriers retained in the pool of suppliers, given that F_k is the fixed cost of operating with a given carrier.

3.3.2 Capacitated model

In this case, the decision variable is integer and represents the number of trips assigned to the carrier. The constraints change somewhat:

$$\begin{cases} \sum_j^m x_{i,j} \geq r_i, & \forall i, \\ \text{if } c_{i,j} = 0, \Rightarrow x_{i,j} = 0, & \forall i, \forall j, \\ x_{i,j} \leq c_{i,j}, & \forall i, \forall j, . \end{cases} \tag{7}$$

The objective function becomes:

$$C_{cap} = \min\big(\sum_i^n \sum_j^m (x_{i,j} b_{i,j}) + B_k F_k\big), \tag{8}$$

The models can be tuned so as to minimize the number of carriers in the supplier pool by suitably defining the fixed cost F_k. We have enumerated in § 4.2 a number of solution sets by increasing the fixed cost from 0 to a number so large that no further carrier could be culled from the pool of suppliers without violating the trip requirement constraint.

4 Results with a Monte Carlo simulation

We now compare EFM and the AM ex post: once demand has been revealed using two examples.

The shipper initially puts to tender a vector of 10 volumes over the 10 lanes. The volumes are taken from a uniform distribution between 10 and 30. This data is then used to obtain three groups of carriers: the first group is obtained by the Efficient Frontier model (EFM), the second one by the Assignment Model (AM) when the carriers are selected without taking into account their capacities, the fourth is the set of carriers taking into account the capacity limits specified in their bids.

We have to see how the EFM evolves when in presence of two types of population. The first type is homogeneous (HomoPop): all prices quoted by this group of forty carriers come a uniform distribution of prices on a support $[0, 1]$ (see table 2 on page 24). A second population (UnhomPop) is composed of two subgroups: one subgroup of twenty carriers has prices using a uniform distribution along the support $[0.1]$, the other group of twenty has prices coming from a normal distribution $\mathcal{N}(0.5, 0.2)$ (see table 3 on page 25). We look at how the EFM retains the "efficient" carriers using both populations.

Because the carriers are not interested by all the lanes, we have generated a matrix of 400 zeroes and ones uniformly random. The product of this matrix of zeroes and ones by the matrix of existing bids yields a sparse matrix of bids from carriers over lanes.

We next generate two samples of 10 000 vectors of 10 demands over the 10 lanes using two distinct distributions: a uniform and a normal distribution. The uniform distribution is over the segment $[10, 30]$. The normal distribution set has a mean of 20 and standard deviation of 2.5.

4.1 Efficient Frontier Model

In the case of bundled bids, the shipper has at least two problems. One is to *screen* the bids to determine the carriers that he wants to involve in a costly long-term relationships with. The other is to actually *assign* the cargo in a given period with given shipping needs to the chosen carriers. The screening problem can be thought of as an assignment problem with unknown demand.

The solution involves thus a two-step process.

4.1.1 Screening

The output-oriented DEA formulation 2 can help the *screening* task. We may let the columns represent each carrier as a DMU with outputs equal to the bids offered over the lanes times the volumes and the bids of this transportation vector as the input. That is, for some possible demand vector $\tilde{y}$, they may all be part of an optimal assignment. Now of course, if we introduce some more information about the possible demand vectors we can reduce the number of carriers. This corresponds to a DEA using some partial price information.

4.1.2 Trip and lane assignment

Turning now to the *assignment* problem, we must find the cost minimal combination of carriers that can cover the transportation need on the 10 different lanes. However, this is equivalent to the input based, cost minimization problem described in (1) in section 3.1. We solve for the minimal cost corresponding to an output vector y equal to the forecast demand. We obtain a set of 8 carriers when taken from HomPop. For each carrier we get a proportion of trips for each lane. For example, carrier 2 gets to carry what capacity he bid on lane 5 only. For Carrier 21, the calculation is slightly more complicated: out of all the volume attributed to him, 75% will come from trips on lane 7, 10% will come from both lanes 4 and 5, 4% will come from lane 10 and 1% will come from lane 8. (see Table 4 on page 26).

4.2 Assignment Model

As mentioned in the description of the model, we use a fixed cost of operation for each carrier included in the pool of transport providers. This fixed cost can be construed as an administrative cost supported by the shipper and which includes the cost of monitoring the carrier's performance, communicating with him and other administrative overheads. By increasing this fixed cost, we progressively make it uneconomical to include many carriers. We plot in figure 2 on the next page the fixed cost and the overall transport cost given this reduced number of carriers when they care considered to be uncapacitated. For comparison purposes, the fixed cost has in fact been taken out of this cost. At a certain level, the number of carriers cannot be decreased any further without violating the lane and number of trips requirements. The share of overall transport cost attributed to each carrier retained in the pool of suppliers when its maximum number is progressively reduced is presented in Table 5 on page 27.

The *minimum minimorum* is achieved with only 2 carriers: with less than that number, some lanes would not be served.

4.3 Results

Once the assignments are made, how does the transport cost evolve under different volume realizations? Which method provides the most robust set of suppliers under varying conditions of demands?

We evaluate the resulting variable cost (excluding the fixed cost which helped us select the carriers) using sets of ten thousand random vectors of demand and give in table 4 the resulting average and variance of

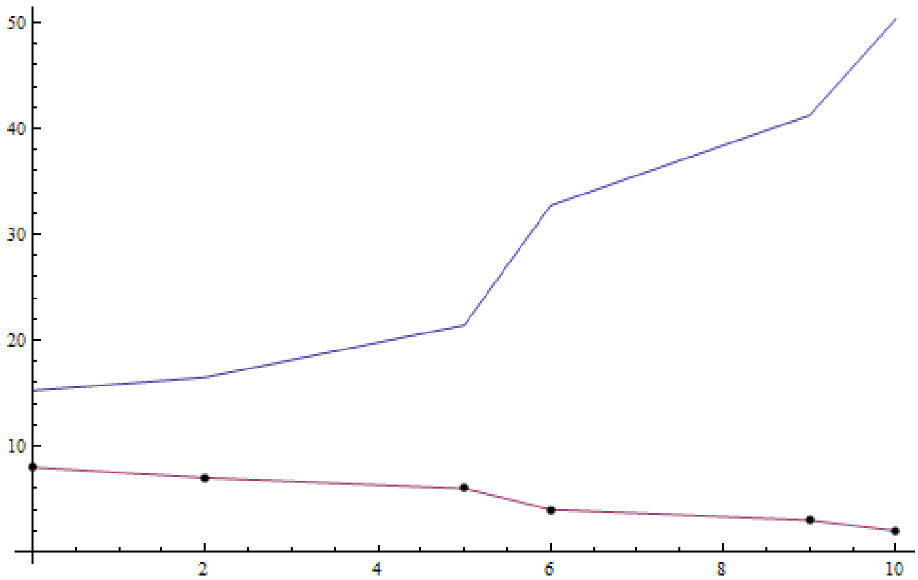

Figure 2: The graph plots the evolution of the transport cost (excluding fixed cost, top curve) when the fixed cost increases and the number of carriers decreases (bottom curve and points).

the total cost to the shipper. Two samples were generated: one with uniform distribution with support on [10,30] and the other a normal distribution with mean 20 and standard deviation 2.5. We further considered two options: the shipper attributes the volumes to the elected carriers in the pool without consideration of capacity or she attributes the volumes taking into account the capacities they had advertised in their bids. When uncapacitated, the lowest bidder on each destination is retained. When the carriers are capacitated, the lowest bidder gets the most trips till his capacity is filled, the remaining requirement is transferred to the second bidder and if this carrier's capacity is also filled, the remaining requirement is passed on to the third bidder, etc till the total requirement is filled (see table 5).

5 Managerial insight of the outcome

This brings us to the whole purpose of screening the carriers using the non-parametric frontier method in the first place: when the shipper

8 carriers		AM		EFM		Δ%
Cap	Uniform	Mean :	17.66	Mean:	32.68	+85%
		Var. :	7.41	Var. :	14.54	
		Max:	26.34	Max:	45.97	
		Min: 9.05		Min: 21.15		
	Normal	Mean :	17.66	Mean :	32.64	+85%
		Var. :	7.41	Var. :	2.81	
		Max:	26.34	Max:	40.30	
		Min: 9.05		Min: 26.84		
Uncap	Uniform	Mean :	5.11	Mean :	9.17	+79%
		Var. :	0.70	Var. :	1.29	
		Max:	7.28	Max:	12.60	
		Min: 2.93		Min: 5.61		
	Normal	Mean :	5.10	Mean :	9.16	+80%
		Var. :	0.12	Var. :	0.22	
		Max:	6.56	Max:	11.15	
		Min: 3.75		Min: 7.38		

Table 1: Results for each pool of capacitated and uncapacitated retained carriers of averaging the transport cost over 10 000 realizations of vectors of demands when uniformly and normally distributed when the initial population of carriers were from an undifferentiated population (HomPop).

“knows” which of his carriers are “efficient”, he will direct to them any requirement which were not initially included in the tender. These include increased frequencies, different trucks or last-minute rush jobs. An unforeseen event can also be a reduction in the number of trips to be made per period. Some carriers might take advantage of such a reduction to renegotiate the conditions of their participation in the pool of suppliers. The shipper would be in a better bargaining position if she knew the position of the carrier on the technological efficiency frontier.

By using the non-parametric frontier method, the logistics manager knows that his retained bidders are efficient. He may in a second phase decide to favour them by enticing them to submit new bids on the lanes in the regions in which they have been identified as being efficient, for example for controlled temperature cargo.

One of the interesting features of the EFM is that the shipper is protected against ex post holdup situations where he might be a victim of predatory pricing practised by non-efficient carriers in cases unforeseen in the ex ante tender.

There clearly is a tradeoff between efficiency and cost. As can be seen in table 4, the extra cost of retaining the efficient carriers versus the cheapest ones in our simulation amounts to $79 - 85\%$ over the cheaper alternative. Our controlled setting here does not suppose that the carriers do not hold up the shipper.

In conclusion, the EFM may be of interest to select the efficient carriers, but further research has to be done into which parameters to include and designing an auction where the statistical data across all bidders are of the same order of magnitude.

6 Conclusion

In this paper, we have considered the situation of negative externalities on the demand side in the number of providers, such as relationship specific costs and/or fixed contracting costs. We have shown that a non-parametric screening by an output-oriented formulation of the combinatorial bids can help to find a minimal subset of providers that span the tendered task and minimizes the information rents under externalities.

We have shown that this method entails a higher overall cost to the shipper than a parametric method. The simulation over a sample of randomly generated demands proves that. The comparison presented here however cannot capture the extra benefits of the non-parametric method like increased efficiency or increased ability by the carriers to stretch their offers to better suit the shipper's varying transport requirements. Our example further is generated using a random number generator and real life situations would provide data which show significant differences between carriers. The choice of the efficient ones would thus generate slightly better results.

Besides this normative interpretation, that may serve as a starting point in a possible qualitative evaluation of the service providers, a more game theoretic interpretation can be sketched for the discussion.

Exploiting the high matching costs, a strategic provider may try to signal an artificially low price (the *decoy*) for a route to attract a shipper in anticipation of other (unassigned) volumes at non-competitive rates. A link-wise auction would fall into such traps and potentially induce high switch-over or lock-in costs, whereas the non-parametric formulation promotes balanced offers that span a larger service spectrum.

The deployment of frontier analysis to assess the bidding production function furthermore enables the buyer to analyze potentially "soft" lanes where the relative price per kilometre is significantly above the estimated cost norm. This situation may indicate the existence of return cargo which may be the preserve of some carriers. Depending on relative and absolute size in the market, the shipper may have the possibility to act upon such occurrences by promoting market development, e.g. by declaring multi-carrier selections in a RFP or by directly or indirectly supporting other providers to offer the particular services. This line of thought, which is not developed here, could be pursued effectively using a parametric approach, such as the stochastic frontier analysis (SFA), to estimate the underlying cost function.

Further research intends to establish whether the formulation has empirical behavioural support by validation using actual assignments and bidding patterns in other transport auctions. An additional issue of interest can be the development of the model to take into account effects such as the past reactions to exogenous shocks (fuel prices, delays) in an inter-temporal framework, which might form the basis of a forward-looking assignment system based on revealed service performance.

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8 Appendix

Lane	1	2	3	4	5	6	7	8	9	10
Carrier 1	0.825	0.817	0	0.587	0	0	0.474	0.69	0	0
Carrier 2	0	0.118	0	0.194	0	0.337	0.701	0.002	0.506	0
Carrier 3	0	0	0	0.755	0.028	0.254	0.659	0.724	0.89	0
Carrier 4	0.101	0.834	0.523	0.465	0	0	0	0.631	0	0
Carrier 5	0	0	0.593	0	0	0	0	0.72	0.516	0
Carrier 6	0	0.734	0	0	0	0	0.896	0.797	0.127	0.11
Carrier 7	0	0	0.772	0.248	0	0.005	0.825	0.601	0.294	0
Carrier 8	0.196	0.692	0.007	0.337	0.709	0.991	0	0.832	0.823	0
Carrier 9	0	0.443	0	0.073	0.928	0.62	0	0	0.093	0
Carrier 10	0	0.054	0.828	0.727	0.788	0.178	0	0	0	0
Carrier 11	0.449	0	0	0.189	0	0.595	0	0	0.962	0
Carrier 12	0	0.201	0.374	0.992	0	0.32	0.927	0.085	0.624	0
Carrier 13	0.425	0	0.532	0	0.938	0.267	0	0.137	0	0.644
Carrier 14	0	0.447	0.534	0.5	0	0	0.667	0.572	0	0.097
Carrier 15	0	0.009	0	0.475	0	0	0.632	0.748	0	0.019
Carrier 16	0.681	0	0	0.519	0	0.904	0	0.337	0.162	0.847
Carrier 17	0.145	0.392	0.148	0.225	0	0	0	0.531	0.423	0.698
Carrier 18	0	0	0	0	0	0.442	0.259	0.686	0.101	0.467
Carrier 19	0	0.6	0	0.93	0	0.357	0.771	0	0	0.689
Carrier 20	0.003	0	0.515	0.761	0.624	0.186	0	0	0	0
Carrier 21	0	0	0	0.124	0.221	0	0.047	0.109	0	0.295
Carrier 22	0.873	0	0	0	0.441	0.974	0.914	0.723	0	0
Carrier 23	0	0	0.073	0.211	0.348	0.691	0	0	0	0
Carrier 24	0	0.138	0	0.278	0	0.412	0.127	0	0	0
Carrier 25	0.766	0.468	0	0	0.399	0	0	0	0.996	0.878
Carrier 26	0.487	0.078	0	0	0	0	0	0.328	0.613	0
Carrier 27	0	0	0	0.035	0	0	0.518	0	0	0.847
Carrier 28	0	0	0	0.369	0	0	0.09	0.827	0	0
Carrier 29	0.439	0.785	0	0.23	0	0.294	0	0.107	0	0.982
Carrier 30	0	0	0.507	0	0	0.619	0	0.545	0	0
Carrier 31	0.494	0.19	0	0	0	0	0	0.623	0.245	0.387
Carrier 32	0.809	0.393	0	0.069	0	0	0.592	0	0	0
Carrier 33	0.416	0	0	0	0	0	0	0	0	0.118
Carrier 34	0	0	0.194	0.941	0	0.204	0.686	0	0	0
Carrier 35	0	0	0	0	0.545	0	0	0.573	0.655	0.854
Carrier 36	0	0	0	0	0	0.346	0	0.413	0	0
Carrier 37	0	0	0	0.395	0	0.433	0	0.409	0.104	0
Carrier 38	0	0.54	0	0.999	0	0	0.166	0	0	0.729
Carrier 39	0	0.998	0	0	0.561	0.345	0	0.195	0.023	0
Carrier 40	0	0	0.029	0	0	0	0	0.913	0.689	0

Table 2: Carrier bids over the lanes which are the basis for both the AM and the EFM simulations in HomPop.

Lane	1	2	3	4	5	6	7	8	9	10
Carrier 1	0.994	0.643	0	0.997	0	0	0.825	0.136	0	0
Carrier 2	0	0.649	0	0.818	0	0.613	0.641	0.128	0.477	0
Carrier 3	0	0	0	0.713	0.598	0.887	0.105	0.959	0.17	0
Carrier 4	0.447	0.242	0.685	0.112	0	0	0	0.6	0	0
Carrier 5	0	0	0.202	0	0	0	0	0.318	0.52	0
Carrier 6	0	0.418	0	0	0	0	0.97	0.867	0.611	0.0791
Carrier 7	0	0	0.231	0.847	0	0.308	0.381	0.607	0.0998	0
Carrier 8	0.244	0.253	0.337	0.049	0.491	0.283	0	0.45	0.0255	0
Carrier 9	0	0.86	0	0.291	0.607	0.653	0	0	0.235	0
Carrier 10	0	0.445	0.743	0.118	0.335	0.138	0	0	0	0
Carrier 11	0.599	0	0	0.869	0	0.905	0	0	0.512	0
Carrier 12	0	0.166	0.214	0.696	0	0.818	0.897	0.488	0.435	0
Carrier 13	0.411	0	0.66	0	0.82	0.84	0	0.481	0	0.798
Carrier 14	0	0.736	0.684	0.115	0	0	0.218	0.702	0	0.81
Carrier 15	0	0.769	0	0.929	0	0	0.0742	0.94	0	0.65
Carrier 16	0.306	0	0	0.983	0	0.605	0	0.0477	0.174	0.679
Carrier 17	0.867	0.714	0.571	0.0698	0	0	0	0.666	0.36	0.463
Carrier 18	0	0	0	0	0	0.17	0.412	0.196	0.39	0.486
Carrier 19	0	0.00681	0	0.762	0	0.188	0.851	0	0	0.712
Carrier 20	0.233	0	0.459	0.366	0.072	0.723	0	0	0	0
Carrier 21	0	0	0	0.284	0.529	0	0.593	0.705	0	0.507
Carrier 22	0.349	0	0	0	0.57	0.694	0.634	0.707	0	0
Carrier 23	0	0	0.61	0.805	0.769	0.429	0	0	0	0
Carrier 24	0.672	0.534	0	0.383	0	0.481	0.476	0	0	0
Carrier 25	0.327	0.725	0	0	0.831	0	0	0	0.303	0.396
Carrier 26	0.601	0.352	0	0	0	0	0	0.418	0.663	0
Carrier 27	0	0	0	0.743	0	0	0.243	0	0	0.524
Carrier 28	0	0	0	0.705	0	0	0.566	0.594	0	0
Carrier 29	0.714	0.477	0	0.533	0	0.799	0	0.572	0	0.372
Carrier 30	0	0	0.576	0	0	0.448	0	0.618	0	0
Carrier 31	0.542	0.65	0	0	0	0	0	0.711	0.621	0.564
Carrier 32	0.567	0.454	0	0.234	0	0	0.313	0	0	0
Carrier 33	0.369	0	0	0	0	0	0	0	0	0.575
Carrier 34	0	0	0.48	0.303	0	0.2	0.559	0	0	0
Carrier 35	0	0	0	0	0.401	0	0	0.688	0.315	0.501
Carrier 36	0	0	0	0	0	0.737	0	0.288	0	0
Carrier 37	0	0	0	0.295	0	0.574	0	0.353	0.541	0
Carrier 38	0	0.515	0	0.299	0	0	0.455	0	0	0.44
Carrier 39	0	0.452	0	0	0.418	0.784	0	0.431	0.28	0
Carrier 40	0	0	0.0772	0	0	0	0	0.749	0.518	0

Table 3: Carrier bids over the lanes which are the basis for both the AM and the EFM simulations in UnhomPop.

DMU	Inverted score	$F_o(x, y)$	1	2	3	4	5	6	7	8	9	10
Carrier 1	0.1266	7.899	0	0	0	0	0	0	0	0	0	0
Carrier 2	1	1	0	0	0	0	0	0	0	1	0	0
Carrier 3	1	1	0	0	0	0	1	0	0	0	0	0
Carrier 4	0.0812	12.313	0	0	0	0	0	0	0	0	0	0
Carrier 5	0.1074	9.312	0	0	0	0	0	0	0	0	0	0
Carrier 6	0.3909	2.558	0	0	0	0	0	0	0	0	0	0
Carrier 7	1	1	0	0	0	0	0	0.99	0	0	0	0
Carrier 8	1	1	0	0	0.95	0.02	0.02	0	0	0	0	0
Carrier 9	0.5739	1.743	0	0	0	0	0	0	0	0	0	0
Carrier 10	0.2698	3.706	0	0	0	0	0	0	0	0	0	0
Carrier 11	0.1822	5.489	0	0	0	0	0	0	0	0	0	0
Carrier 12	0.1402	7.130	0	0	0	0	0	0	0	0	0	0
Carrier 13	0.1027	9.737	0	0	0	0	0	0	0	0	0	0
Carrier 14	0.2460	4.065	0	0	0	0	0	0	0	0	0	0
Carrier 15	1	1	0	0.71	0	0	0	0	0.01	0	0	0.28
Carrier 16	0.1737	5.757	0	0	0	0	0	0	0	0	0	0
Carrier 17	0.1767	5.660	0	0	0	0	0	0	0	0	0	0
Carrier 18	0.4427	2.259	0	0	0	0	0	0	0	0	0	0
Carrier 19	0.1093	9.149	0	0	0	0	0	0	0	0	0	0
Carrier 20	0.2336	4.280	0	0	0	0	0	0	0	0	0	0
Carrier 21	1	1	0	0	0	0.1	0.1	0	0.75	0.01	0	0.04
Carrier 22	0.1237	8.087	0	0	0	0	0	0	0	0	0	0
Carrier 23	0.4320	2.315	0	0	0	0	0	0	0	0	0	0
Carrier 24	1	1	0.95	0.01	0	0	0	0	0.04	0	0	0
Carrier 25	0.1274	7.849	0	0	0	0	0	0	0	0	0	0
Carrier 26	0.1918	5.213	0	0	0	0	0	0	0	0	0	0
Carrier 27	1	1	0	0	0	0.99	0	0	0	0	0	0.01
Carrier 28	0.8707	1.149	0	0	0	0	0	0	0	0	0	0
Carrier 29	0.1201	8.325	0	0	0	0	0	0	0	0	0	0
Carrier 30	0.0592	16.898	0	0	0	0	0	0	0	0	0	0
Carrier 31	0.1447	6.912	0	0	0	0	0	0	0	0	0	0
Carrier 32	0.4445	2.250	0	0	0	0	0	0	0	0	0	0
Carrier 33	0.4140	2.416	0	0	0	0	0	0	0	0	0	0
Carrier 34	0.2015	4.962	0	0	0	0	0	0	0	0	0	0
Carrier 35	0.1486	6.730	0	0	0	0	0	0	0	0	0	0
Carrier 36	0.0565	17.689	0	0	0	0	0	0	0	0	0	0
Carrier 37	0.3532	2.831	0	0	0	0	0	0	0	0	0	0
Carrier 38	0.3734	2.678	0	0	0	0	0	0	0	0	0	0
Carrier 39	1	1	0	0	0	0	0.01	0	0	0	0.98	0
Carrier 40	0.7025	1.423	0	0	0	0	0	0	0	0	0	0

Table 4: EFM results for screening and freight assignment in HomPop, only 8 carriers are retained.

	Trips	Carrier : number of trips		
Lane 1	14	8 : 6	20 : 8	–.–
Lane 2	28	12 : 13	19 : 15	–.–
Lane 3	19	5 : 13	40 : 6	–.–
Lane 4	26	4 : 2	8 : 10	17 : 14
Lane 5	13	20 : 13	–.–	–.–
Lane 6	25	10 : 13	18 : 11	19 : 1
Lane 7	27	3 : 18	15 : 9	–.–
Lane 8	25	1 : 8	2 : 10	16 : 7
Lane 9	27	3 : 3	7 : 16	8 : 8
Lane 10	10	6 : 6	29 : 4	–.–

Table 5: Table of lane attribution in AM when the carrier's trip capacity is taken into account as the fixed cost is 0.